Linda Bagby
Engineering Note

Date: 1.17.2012
Rev Date:

Project: Microboone General Support
Doc. No: B011712A_Bagby_PMT_TS_PAB

Subject: Electrical safety documentation required to obtain ORC approval of PMT test stand at PAB

Introduction:

The Microboone Photomultiplier Tube (PMT) test stand consists of one electronics rack and a cryogenic vessel in which PMTs are submerged in liquid Nitrogen. The test stand is used to characterize the operation of the PMTs which will be used in the experiment. Recent gain studies have shown that the PMTs require a longer amount of time to stabilize than what was expected. Therefore, we seek Operational Readiness Clearance to operate the test stand unattended.

Location:

The MicroBoone test stand is located in the Proton Assembly Building (PAB), shown in Figure 1.

Figure 1: Picture of test stand (rack and vessel).

The electronics rack houses a VME HV crate with a mother board containing high voltage ‘pods’ and the supporting VME infrastructure. The VME HV module and pods were developed by Fermilab for DZero Run 1 and were once commercially available from BiRa Corporation, Model 4877PS. In addition to the VME HV crate, the rack contains a commercially available LAMBDA power supply, +5V Interlock power supply, network switch, and a fan tray. The device under test, Hamamatsu R5912-02, is located inside the cryogenic vessel. Specifications for the PMT are in Appendix A.

AC Distribution:

AC power is provided to the LAMBDA supply, +5V Interlock power supply, network switch, and fan tray by the switched power sources in the SurgeX SX1120RT Surge Suppressor AC Distribution unit. The specifications for the SurgeX can be found in Appendix B. Figure 3 illustrates the AC Distribution in the rack. The Lambda supply is fused at 10A and the +5V Lambda Interlock supply is fused at .5A. The Network switch is a commercial unit.

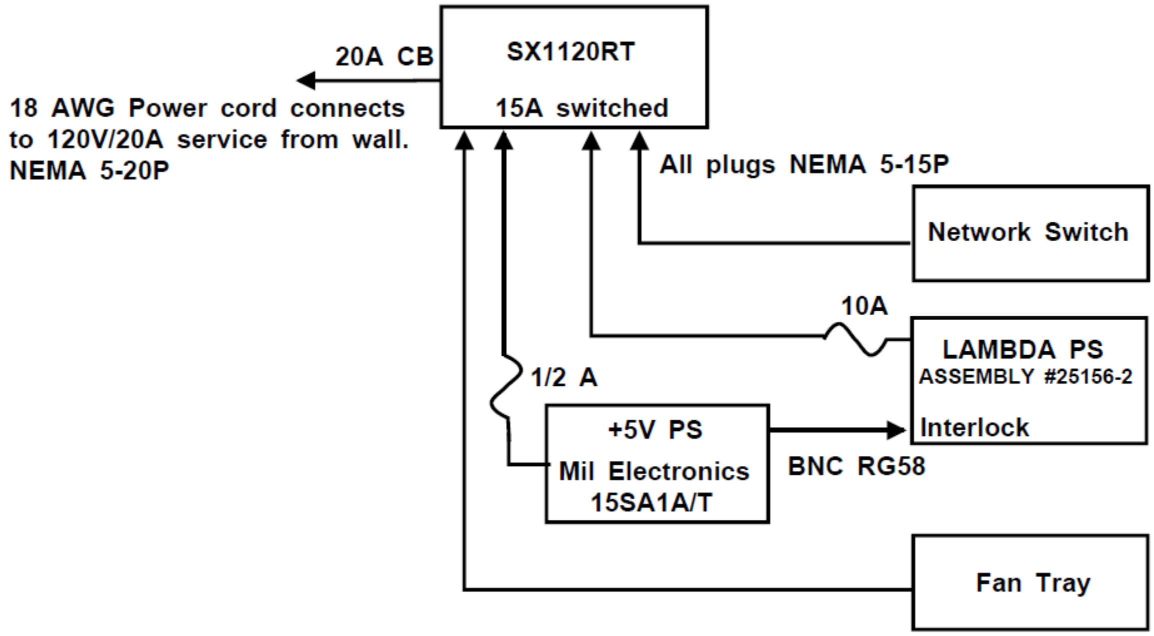


Figure 3: AC Distribution

DC Distribiution:

The LAMBDA power supply assembly # 25156-2, Figure 5, provides DC power to the VME HV crate backplane via a wiring harness which is designed to carry the maximum available current from each supply within the assembly. 10AWG wire is capable of handling 35A and 14 AWG cable is capable of handling 20A. The 14 AWG +5V sense lines are fused at 10A. The harness fusing values and backplane parallel pin designations are shown in Figure 6.

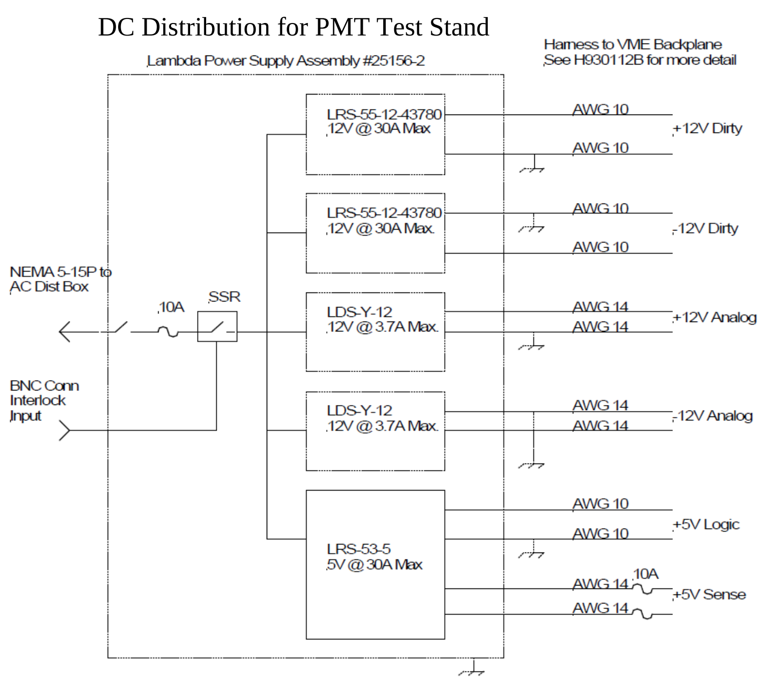
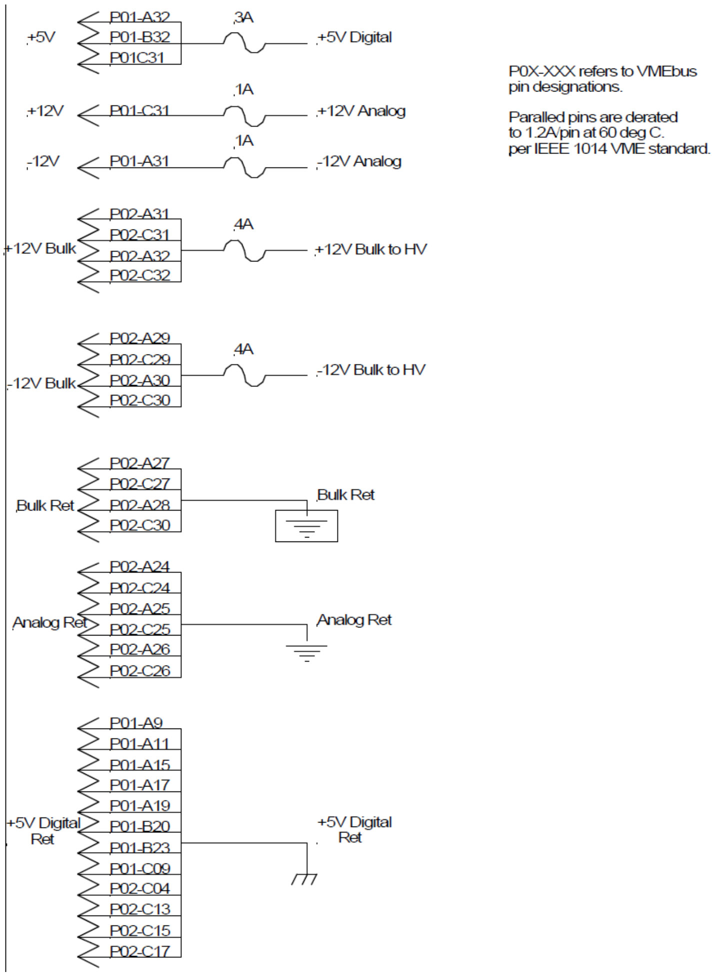


Figure 5: LAMBDA Assembly



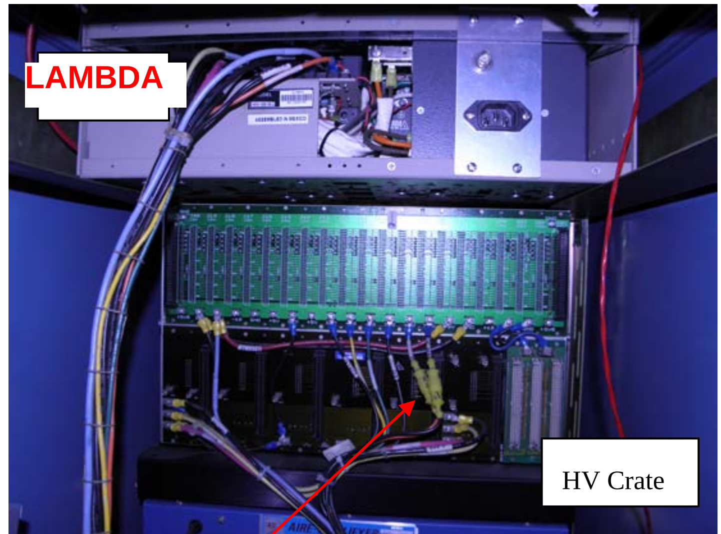


Figure 6: Harness Fusing

The VME HV module is powered by five separate voltages on the crate backplane. These voltages are +5V, +/-12V analog, and +/-12V bulk. Parallel VME pins are used on the +5V and +/-12V supply to limit the current density.

High Voltage Circuit:

The high voltage schematic is shown in Figure 7. The output of the PMT base is connected to the vessel feedthrough with a RG180 cable. This cable is terminate on the base end with a pin to match the base socket (Mill-Max Manufacturing Corp., pin part #: 3117-2-00-21-00-00-08-0, socket part #0326-2-19-15-06-27-10-0). The other end is terminated into a SHV connector which plugs into the feedthrough. The PMT signal is then connected to the Splitter from the warm side of the feedthrough with SHV terminated RG180 cable. The Signal output of the Splitter is connected to a scope (Tektronix TDS5054-NV-T) with a green RG58, BNC terminated cable. The high voltage input of the Splitter is connected to the T4 High Voltage pod (+2kV @ 3mA) with a red RG58, SHV terminated cable. The schematic for the PMT Base is shown in Figure 7.

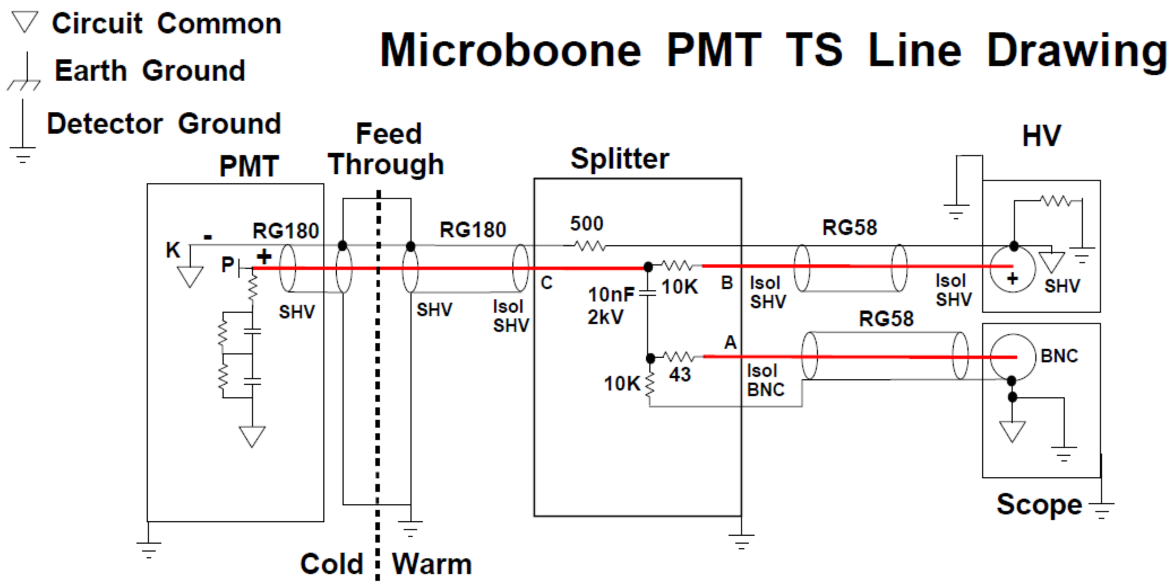
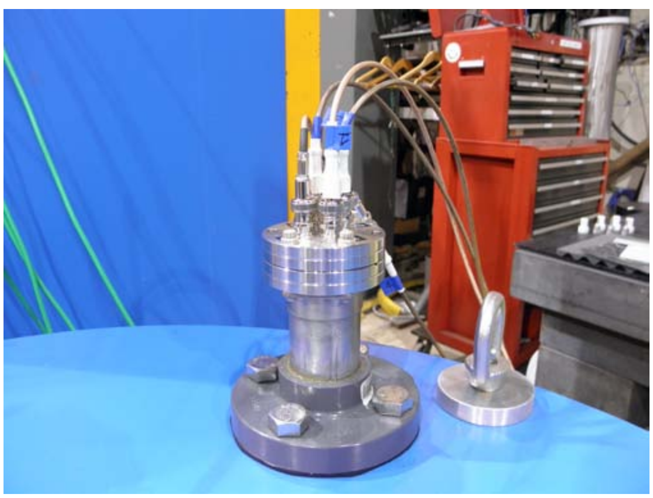
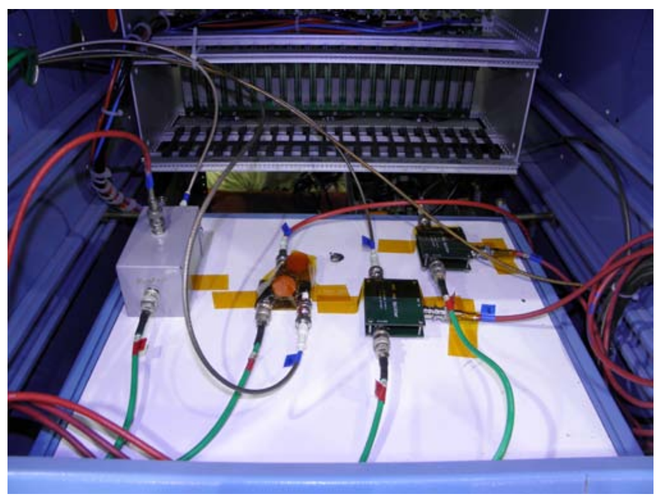


Figure 7: HV Circuit



Cryogenic vessel feedthrough



Splitter circuits

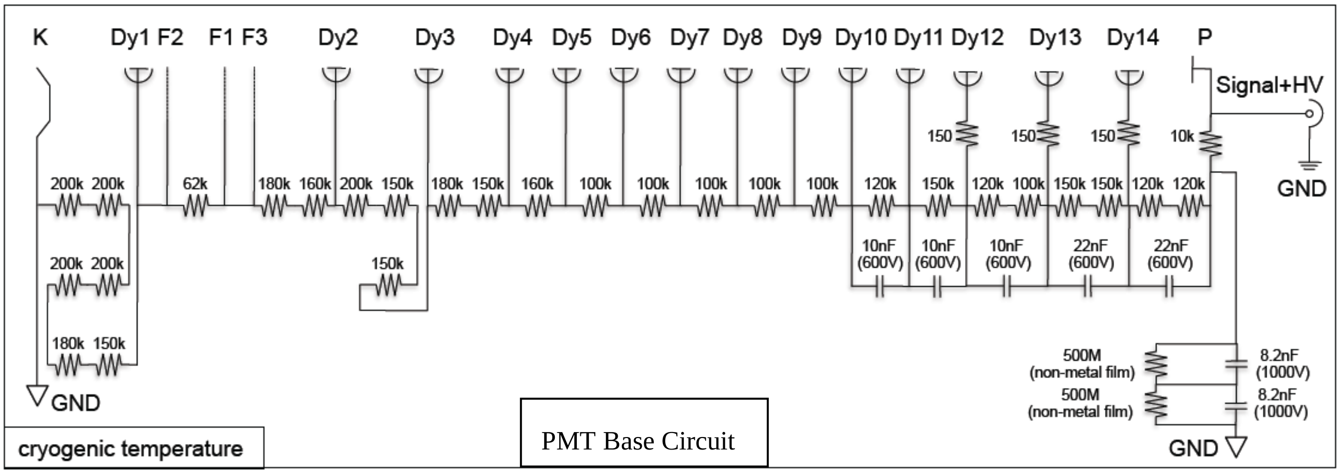


Figure 8:PMT Base circuit schematic.

Voltage Cable Testing:

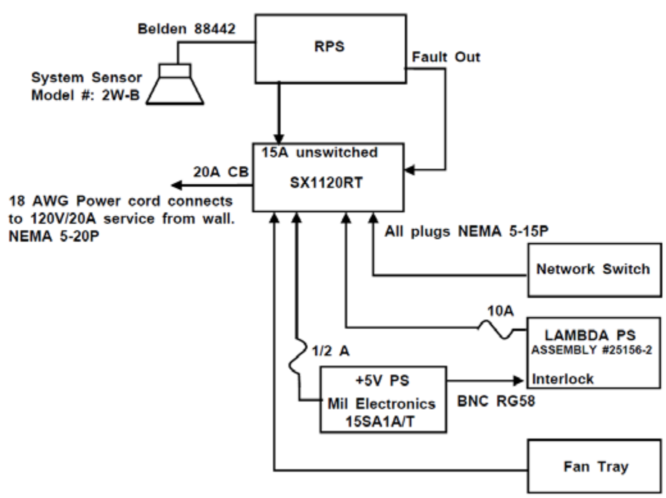
The maximum voltage on the PMTs is 2kV. They are typically biased at 1.7kV. To insure the cable used to connect the PMT base to the cryostat feedthrough will handle the maximum output of the HV Pod, 2kV, RG180 was tested by Walt Jaskierny. The details of his test are in the Microboone DocDB #1806. In summary, Walt measured leakage currents less than 10nA throughout the tested voltage range, 0-8kV. Corona occurred at 9kV.

Cooling:

Forced air cooling is provided by a fan tray located under the VME crate.

Fire Protection:

The electronics are enclosed within a cabinet. The unused slots in the VME crate are covered with panels. Rack Protection is provided with a Rack Protection chassis design by Jamieson Olsen. This chassis is described in Appendix C. Upon detection of smoke, the interlock to the SurgeX AC distribution unit is dropped, whereby AC to the 5V power supply is removed and the LAMBDA power supply turns off.



Shock Hazard:

A Safety Analysis has been written by Marvin Johnson for the D0 High Voltage System. This document is in Appendix D. According to his references, danger from a momentary current pulse is proportional to I^2t. I represents the current in amperes and t represents the time in seconds. The maximum safe value of I^2t for 150 lb man is .027.

The power supply pods used in the PMT System are type T4 which provide +2kV at 3mA. If the output cable of the high voltage pod is shorted with a 1K ohm resistor, representative of a human body, the supply trips off from an over current fault. If the over current fault circuit is disabled, an over voltage fault will occur. Using a conservative trip time and current of 250ms and 50mA, the I^2t value is $6.25\ 10^{-4}$ which provides a safety factor of 43.

The I^2t value due to a stored charge is represented by $V^2C/2R$. V is the pod voltage (2kV), C is the filter capacitor on the pod (3nF), R is the discharge resistance (human body lower limit is 200 Ohms). $I^2t = 3\ 10^{-5}$. Combining this value with the power supply value and dividing into .027 gives a safety factor of 41which includes the double fault condition of a disabled over current circuit and shorting the pod output. With no failures the safety factor is 900.

Another source of stored charge is in the cables connected to the pods. In the test stand, each pod is connected to a single load with two types of cable, RG58 (26.5pF/ft) and RG180 (17.4pF/ft). Each channel has approximately 5 ft of RG58 from the pod to the Splitter circuit. The cable length of RG180 from the Splitter circuit to the feedthrough is 10ft. The RG180 cable length from the feedthrough to the base of the PMT is 5ft. The total capacitance due to cable is 5ft*26.5pF added in parallel with 15ft * 17.4pF for a value of 88pF. This is 34 times smaller than the pod filter capacitor. Therefore, the stored charge contribution due to cable capacitance is negligible.

Appendix A: Hamamatsu Photomultipler Tube Specifications

Appendix B: SurgeX Specifications

Appendix C: Rack Protection

Appendix D: Safety Analysis of the D0 High Voltage System

HAMAMATSU

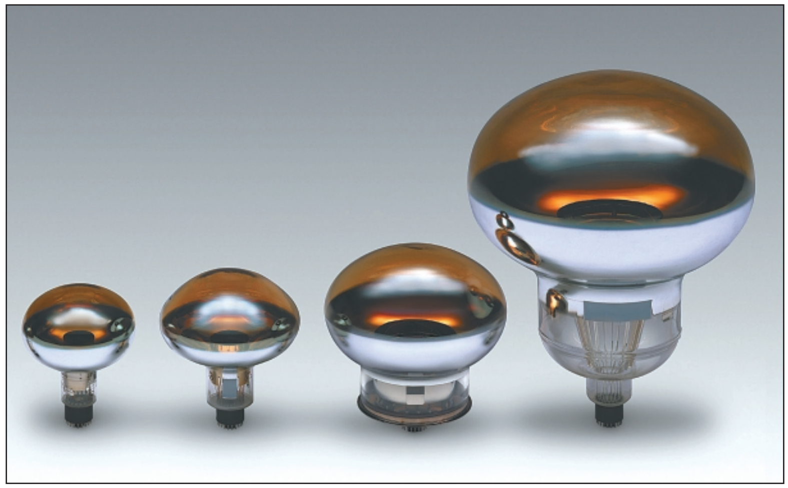
LARGE PHOTOCATHODE AREA PHOTOMULTIPLIER TUBES

APPLICATION

- Neutrino Physics

FEATURES

- Large Photocathode Area
- Fast Time Response
- High Stability
- Less Dark Count



R5912 R5912-02 R7081 R7081-20 R8055 R3600-02 R7250

SPECIFICATIONS

Type No.	Diameter (mm) / (inch)	Minimum Effective Area (mm)	Surface Area Min. (cm²)	Surface Area Typ. (cm²)	Dynode Structure	Dynode Number of Stages	Weight (g)
R5912	202 / 8	ϕ190	330	380	Box & Line	10	approx. 1100
R5912-02	202 / 8	ϕ190	330	380	Box & Line	14	approx. 1100
R7081	253 / 10	ϕ220	470	530	Box & Line	10	approx. 1400
R7081-20	253 / 10	ϕ220	470	530	Box & Line	14	approx. 1400
R8055	332 / 13	ϕ312	960	1080	Box & Line	10	approx. 3000
R3600-02	508 / 20	ϕ460	2030	2410	Venetian blind	11	approx. 8000
R7250	508 / 20	ϕ430	1680	1740	Box & Line	10	approx. 8000

COMMON SPECIFICATIONS

Spectral Response	300 nm to 650 nm
Peak Wavelength	420 nm
Photocathode Material	Bialkali
Window Material	Borosilicate glass

SPECIFICATIONS

Type No.	Cathode Sensitivity: Luminous (2856 K) Min. (µA/lm)	Cathode Sensitivity: Luminous (2856 K) Typ. (µA/lm)	Cathode Sensitivity: Radiant at 420 nm Typ. (mA/W)	Cathode Sensitivity: Blue Sensitivity Index (CS 5-58) Min.	Cathode Sensitivity: Blue Sensitivity Index (CS 5-58) Typ.	Cathode Sensitivity: Quantum Efficiency at 390 nm Typ. (%)	Anode Sensitivity: Luminous (2856 K) Typ. (A/lm)	Anode Sensitivity: Radiant at 420 nm Typ. (A/W)	Anode Sensitivity: Gain Typ.	Anode Sensitivity: Applied Voltage for Typical Gain Typ. (V)
R5912	40	80	80	6.0	10.0	25	700	7.2×10^5	1.0×10^7	1500
R5912-02	40	80	80	6.0	10.0	25	70 000	7.2×10^7	1.0×10^9	1700
R7081	40	80	80	6.0	10.0	25	800	8.0×10^5	1.0×10^7	1500
R7081-20	40	80	80	6.0	10.0	25	80 000	8.0×10^7	1.0×10^9	1700
R8055	35	60	65	5.5	8.0	20	3000	3.25×10^6	5.0×10^7	2000
R3600-02	35	60	65	5.5	8.0	20	600	6.5×10^5	1.0×10^7	2000
R7250	35	60	65	5.5	8.0	20	600	6.5×10^5	1.0×10^7	2000

NOTE: Anode characteristics are measured with the voltage distribution ratio shown below.
(   ): Measured with the special voltage distribution ratio (Tapered Divider) shown below.

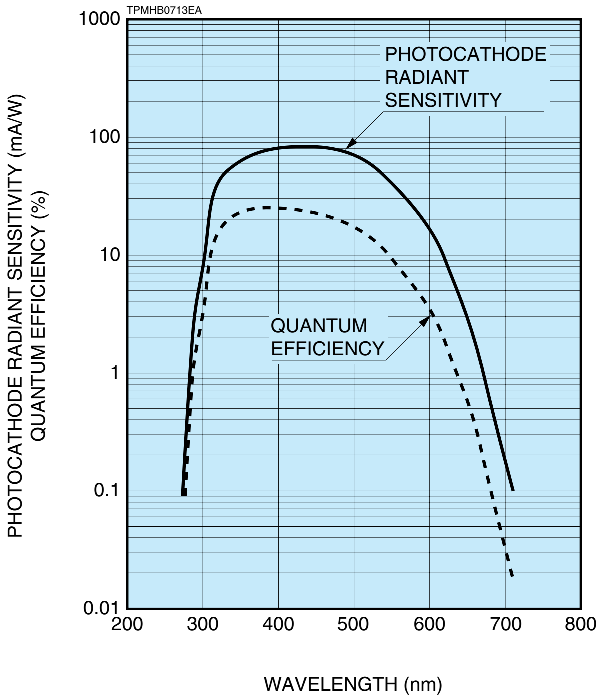
Type No.	Maximum Ratings: Supply Voltage Anode to Cathode (V)	Maximum Ratings: Supply Voltage Anode to Last Dynode (V)	Maximum Ratings: Average Anode Current (mA)	Maximum Ratings: Operating Ambient Temperature (°C)	Maximum Ratings: Storage Temperature (°C)	Maximum Ratings: Ambient Pressure (Gauge) (MPa)	Direct Interelectrode Capacitances: Anode to Last Dynode (pF)	Direct Interelectrode Capacitances: Anode to All Other Dynodes (pF)
R5912	2000	300	0.1	-30 to +50	-30 to +50	0.7	approx. 3	approx. 7
R5912-02	2000	300	0.1	-30 to +50	-30 to +50	0.7	approx. 3	approx. 7
R7081	2000	300	0.1	-30 to +50	-30 to +50	0.7	approx. 3	approx. 7
R7081-20	2000	300	0.1	-30 to +50	-30 to +50	0.7	approx. 3	approx. 7
R8055	2500	300	0.1	-30 to +50	-30 to +50	0.15	approx. 10	approx. 20
R3600-02	2500	300	0.1	-30 to +50	-30 to +50	0.6	approx. 36	approx. 40
R7250	2500	300	0.1	-30 to +50	-30 to +50	0.6	approx. 10	approx. 15

Anode Sensitivity											(at +25 °C)
Dark Current (After 30 min storage in darkness)		Dark Count (After 15 hours storage in darkness)		Time Response			Single Photo-electron (Peak to valley ratio)		Pulse Linearity		Type No.
				Rise Time	Electron Transit Time	Transit Time Spread (FWHM)			at ±2 % Deviation	at ±5 % Deviation	
Typ. (nA)	Max. (nA)	Typ. (s^{-1})	Max. (s^{-1})	Typ. (ns)	Typ. (ns)	Typ. (ns)	Min.	Typ.	Typ. (mA)	Typ. (mA)	
50	700	4000	8000	3.8	55	2.4	1.5	2.5	20 (60)	40 (80)	R5912
1000	5000	6000	12 000	4	68	2.8	1.5	2.5	40	70	R5912-02
50	700	7000	15 000	4.3	63	2.9	1.5	2.5	20 (60)	40 (80)	R7081
1000	5000	9000	19 000	4.5	78	3.3	1.5	2.5	40	70	R7081-20
200	1000	15 000	30 000	5.3	88	2.8	1.5	2.5	60	80	R8055
200	1000	25 000	80 000	10	95	5.5	1.1	1.7	20	40	R3600-02
200	1000	25 000	80 000	7	110	3.5	1.5	2.5	60	80	R7250

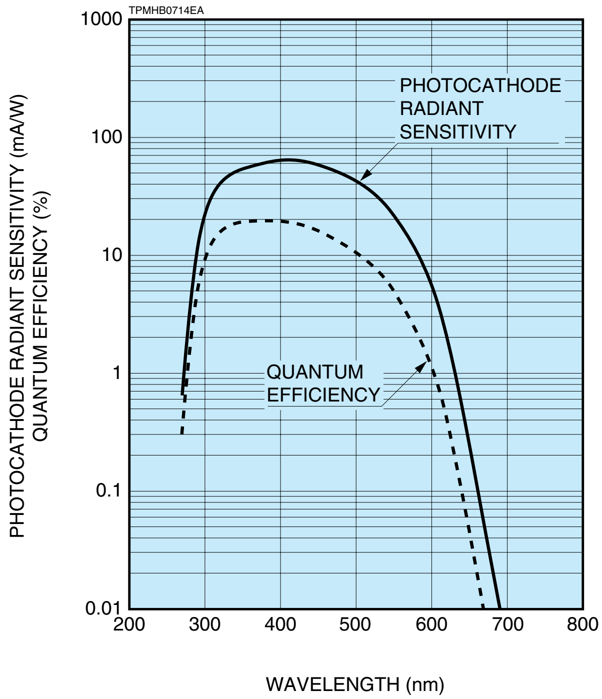
Type No.	Supply Voltage (V)	Voltage Distribution Ratio K: Photocathode Dy: Dynode P: Anode F: Focus																		
		K	Dy1	F2	F1	F3	Dy2	Dy3	Dy4	Dy5	Dy6	Dy7	Dy8	Dy9	Dy10	P				
R5912, R7081	1500	11.3	0	0.6	0	3.4	5	3.33	1.67	1	1	1	1	1	1					
												Capacitors in μF	0.01	0.01	0.01					
R5912, R7081 (Taperd Divider)	1500	11.3	0	0.6	0	3.4	5	3.33	1.67	1	1.2	1.5	2.2	3	2.4					
												Capacitors in μF	0.01	0.01	0.01					
R8055	2000	18.5	0	0.6	0	3.4	5	3.3	1.7	1	1	1	2	3	4					
												Capacitors in μF	0.01	0.01	0.01					
R7250	2000	18.5	0	0.6	0	3.4	5	3.3	1.7	1	1	1	2	3	4					
												Capacitors in μF	0.01	0.01	0.01					
		K	F2	F1	F3	Dy1	Dy2	Dy3	Dy4	Dy5	Dy6	Dy7	Dy8	Dy9	Dy10	Dy11	P			
R3600-02	2000	5	1	2	0.02	3	1	1	1	1	1	1	1	1	1	1				
													Capacitors in μF	0.01	0.01	0.01				
		K	Dy1	F2	F1	F3	Dy2	Dy3	Dy4	Dy5	Dy6	Dy7	Dy8	Dy9	Dy10	Dy11	Dy12	Dy13	Dy14	P
R5912-02	1700	11.3	0	0.6	0	3.4	5	3.33	1.67	1	1	1	1	1	1.2	1.5	2.2	3	2.4	
R7081-20														Capacitors in μF	0.01	0.01	0.01	0.02	0.02	

SPECTRAL RESPONSE CHARACTERISTICS

●R5912, R5912-02
●R7081, R7081-20

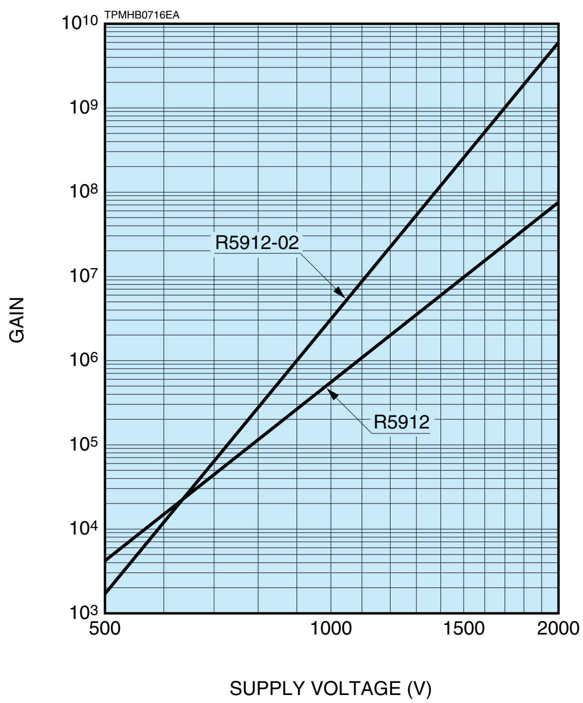


●R8055, R3600-02, R7250

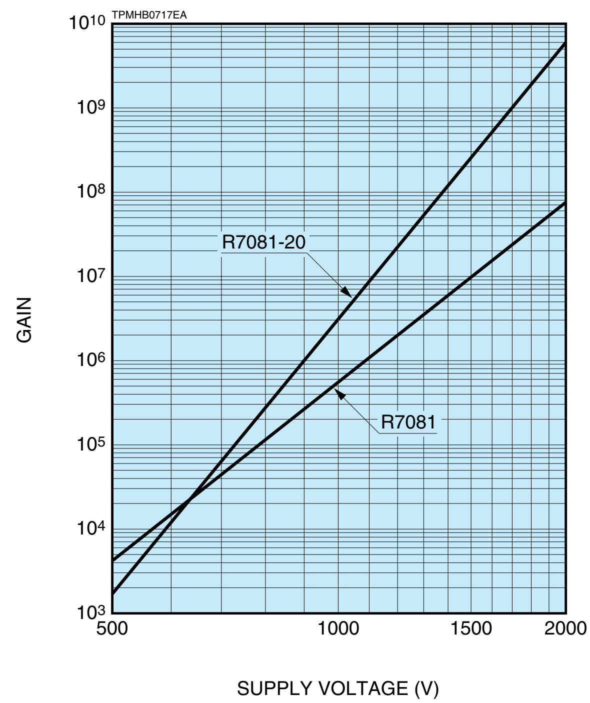


GAIN

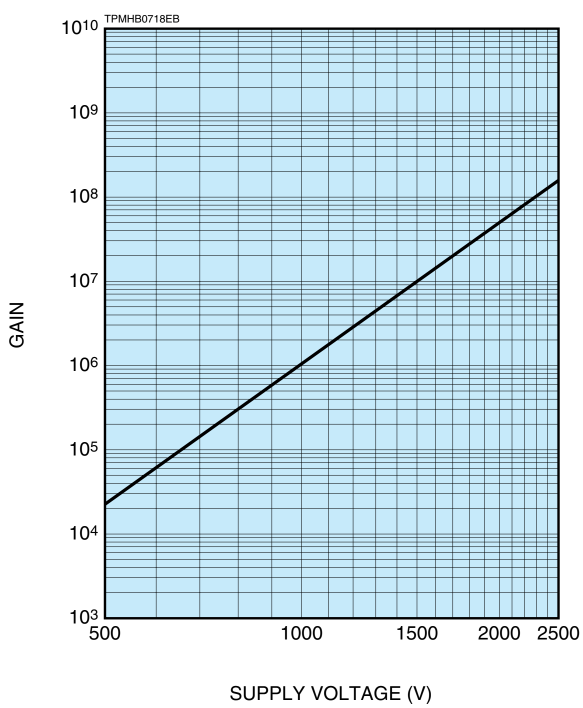
●R5912, R5912-02



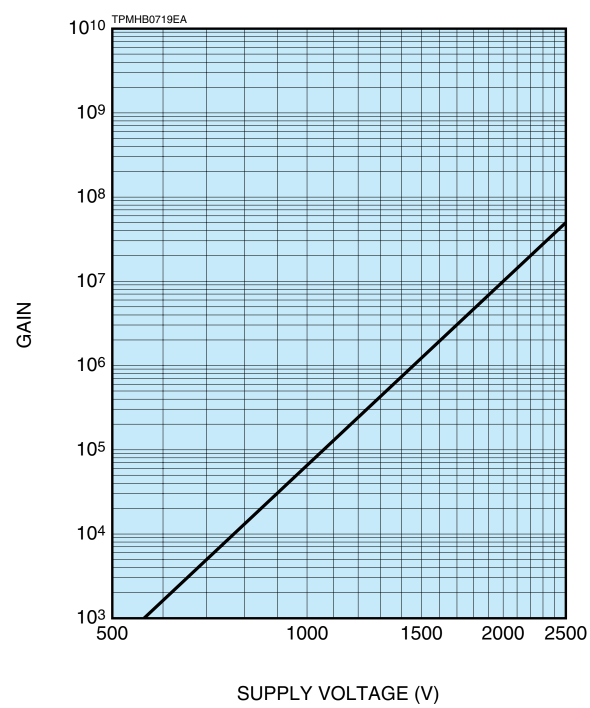
●R7081, R7081-20



●R8055

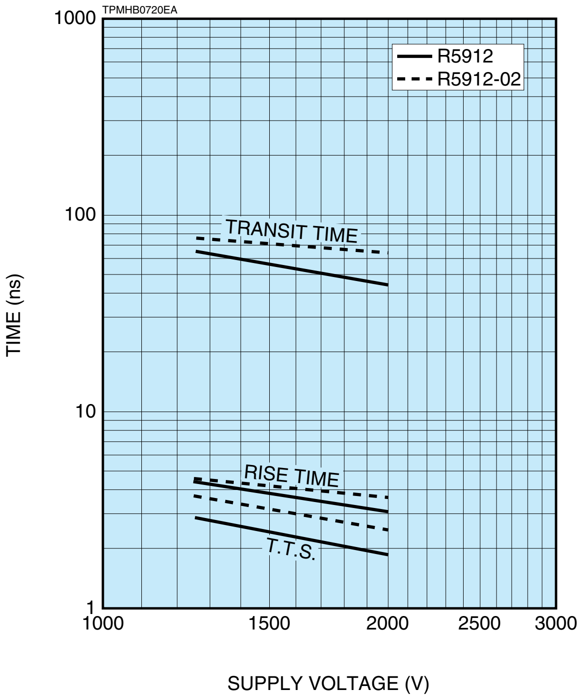


●R3600-02, R7250

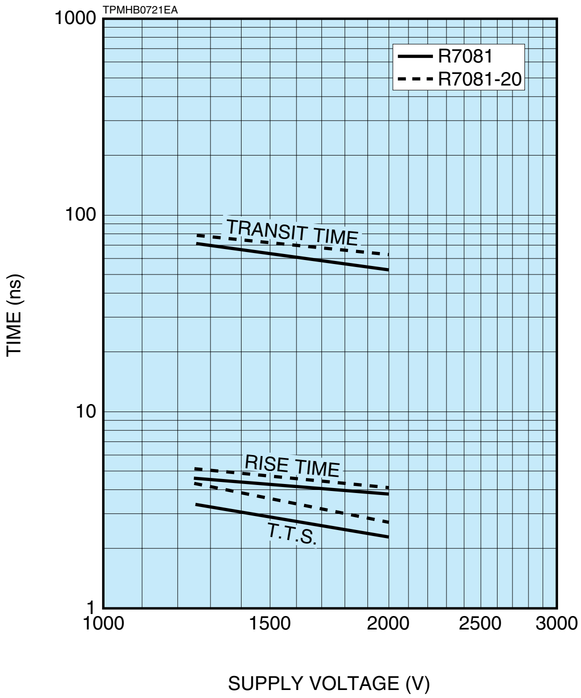


TYPICAL TIME RESPONSE

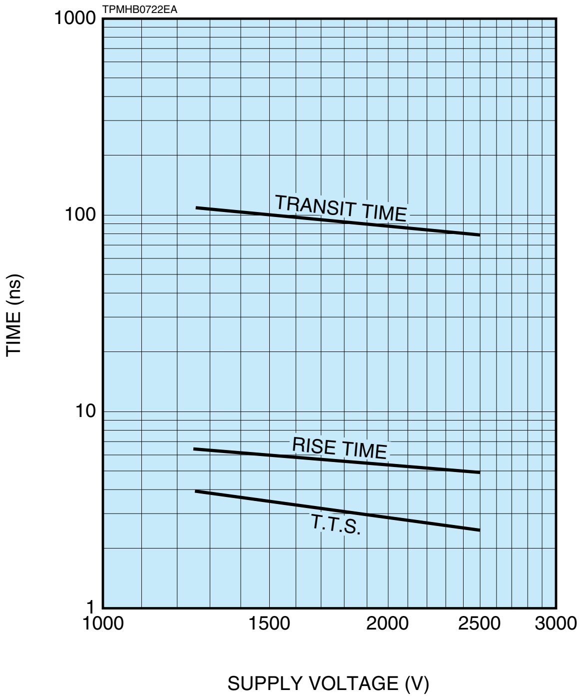
●R5912, R5912-02



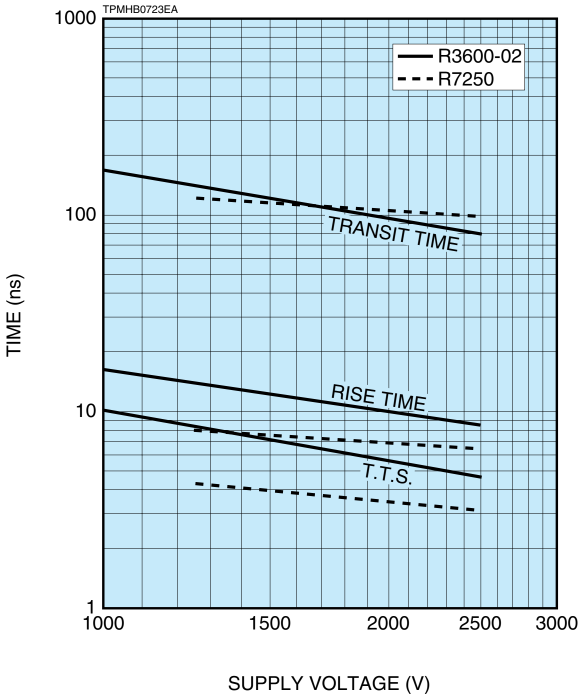
●R7081, R7081-20



●R8055

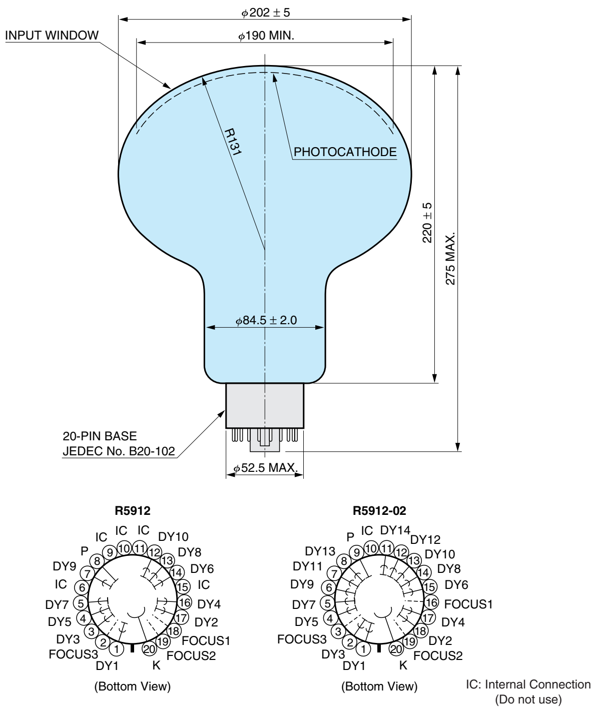


●R3600-02, R7250



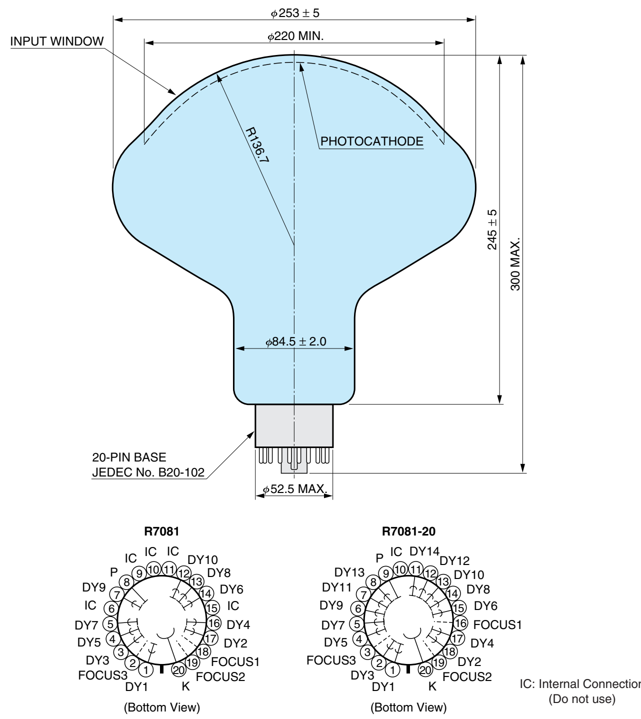
DIMENSIONAL OUTLINE (Unit: mm)

●R5912, R5912-02



TPMHA0500EA

●R7081, R7081-20



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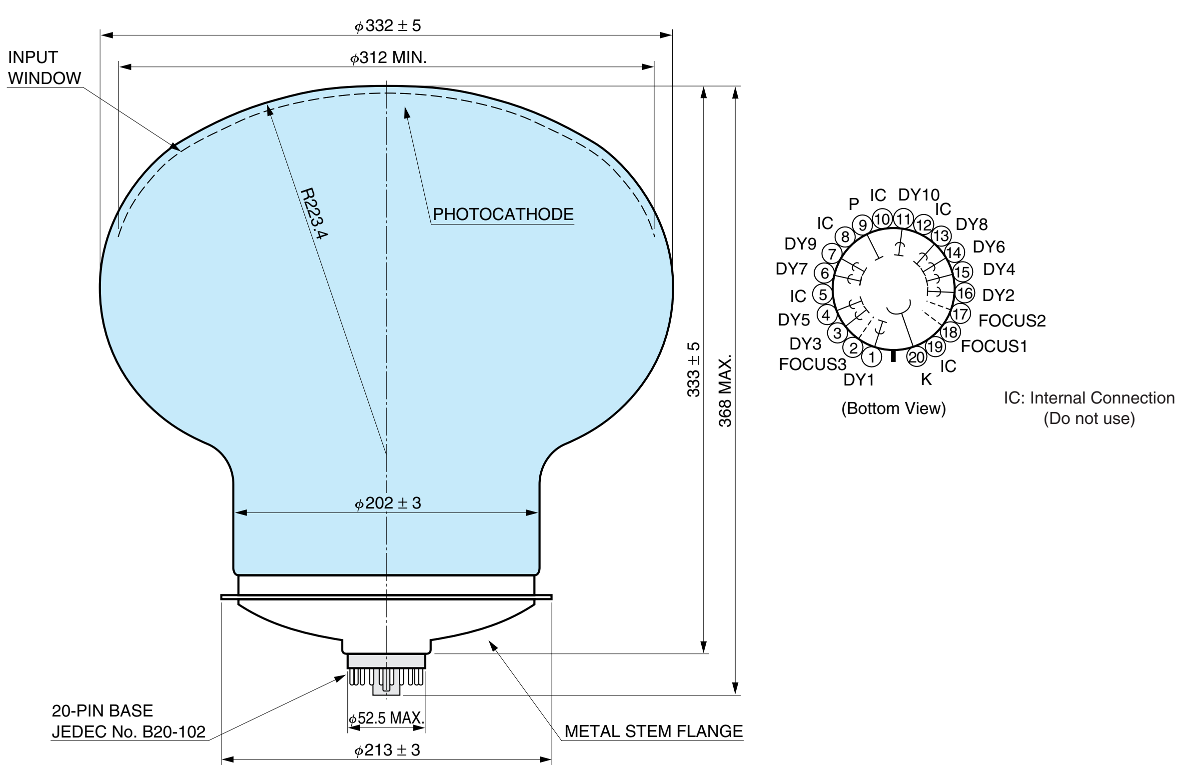
●R8055



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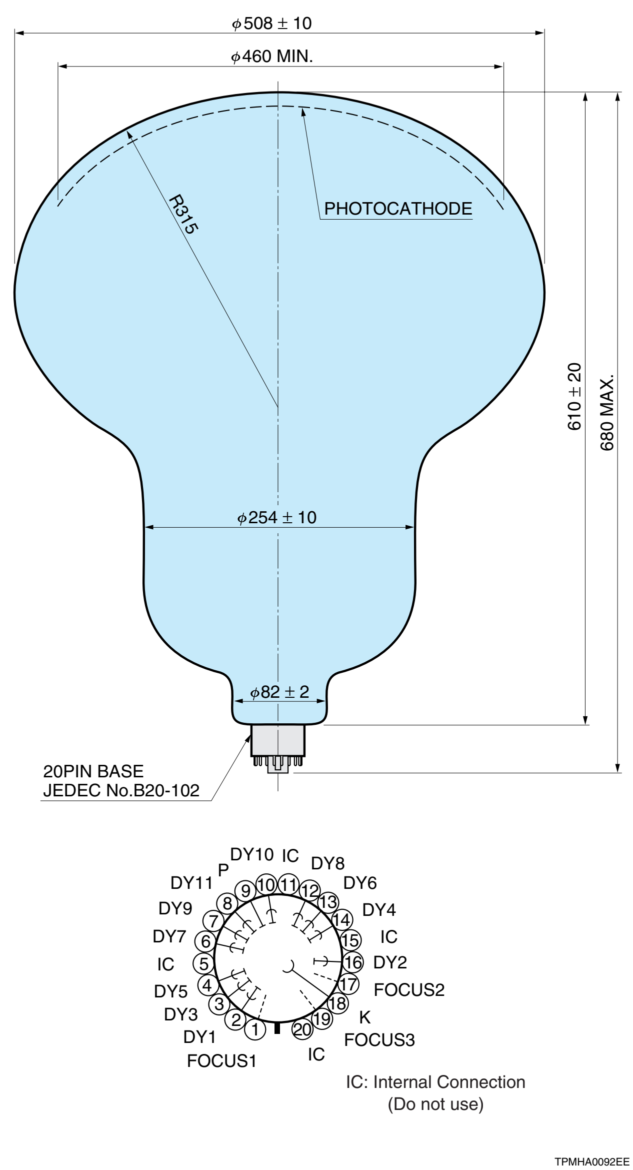
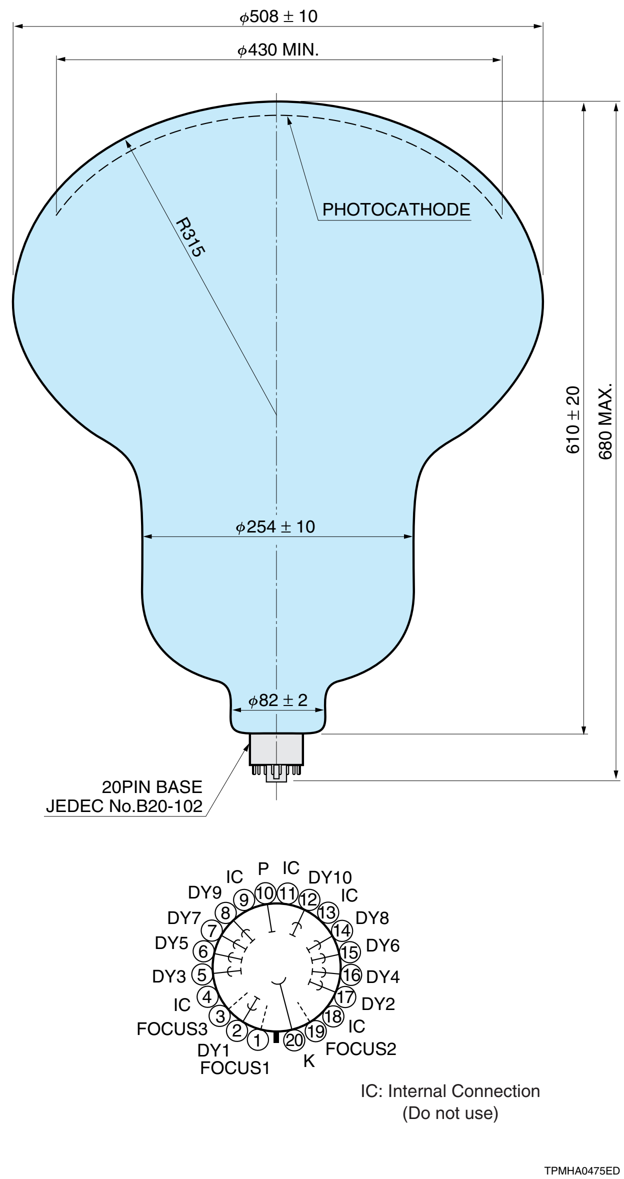
DIMENSIONAL OUTLINE (Unit: mm)

●R3600-02



●R7250



HAMAMATSU

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North Europe: Hamamatsu Photonics Norden AB: Smidesvägen 12, SE-171-41 SOLNA, Sweden, Telephone: (46)8-509-031-00, Fax: (46)8-509-031-01 E-mail: info@hamamatsu.se
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TPMH1286E05
JAN. 2008 IP

SX1120RT SURGE ELIMINATOR & POWER CONDITIONER

With Advanced Series Mode® Surge Protection

Impedance Tolerant® EMI/RFI Filtering

SurgeX ICE® Inrush Current Elimination, and

COUVS® Catastrophic Over/Under-Voltage Shutdown

Switched receptacles can be controlled with an Switched receptacles can be controlled with an applied voltage (5-30 vdc) or contact closure switch connected to the Phoenix connector on the back panel. The connector can also be used to cascade multiple units or provide status to a central controller.

The SX1120RT provides guaranteed surge protection and power conditioning for audio, video, broadcast and computer equipment. The units are 20-amp load-capable and have 8 industrial grade grounded AC receptacles (6 switched, 2 always on) plus a front panel courtesy receptacle.

The unit features both common mode and normal mode *Impedance Tolerant* EMI/RFI filtering, *SurgeX ICE* -Inrush Current Elimination and *COUVS* - Catastrophic Over/Under Voltage Shutdown for a complete power conditioning solution.

SurgeX Advanced *Series Mode* technology is superior to conventional MOV circuitry or MOV-Hybrid designs and is completely non-sacrificial. Our zero let-through technology provides the most reliable protection available. It stops all surges up to 6,000 volts (unlimited surge current) without producing harmful side effects such as ground contamination or common-mode disturbances.

DOWNLOAD SPECS - INSTALLATION GUIDE

The SX1120RT has remote control capability for use in AC power distribution systems and can be interfaced with a sequential controller such as the SurgeX SEQ.

SPECIFICATIONS

Load Rating: 20 amps @ 120 volts

Power Requirement (no load): 15 watts

Surge Let-Through Voltage (6000-volt surge): 0 volts

UL 1449 Adjunct Classification Test Results:
1000 surges, 6000 volts, 3000 amps, B3 pulse.
Measured suppressed voltage: 170 volts, no failures

Federal Guidelines: Grade A, Class 1, Mode 1 (CID A-A-55818)

EMI/RFI Filter, Normal Mode (50-ohm load):
40 dB @ 100 kHz; 50 dB @ 300 kHz;
50 dB @ 3 MHz; 50 dB @ 30 MHz

EMI/RFI Filter, Common Mode (50-ohm load):
18 dB @ 300 kHz; 30 dB @ 1 MHz;
50 dB @ 5 MHz; 50 dB @ 20 MHz

Maximum Applied Surge Voltage: 6000 volts*

Maximum Applied Surge Current:
Unlimited, due to current limiting*

Maximum Applied Surge Energy:
Unlimited, due to current limiting*

Endurance (C62.41-1991 Category B3 pulses):
1 kV>500,000; 3 kV>10,000; 6 kV>1000

Undervoltage Shutdown: 90 volts (resume at 100 v)

Overvoltage Shutdown: 145 volts (resume at 135 v)

Maximum Load Inrush Current During Power-up:
1000 Joules

Remote Turn-on Applied Voltage Range: 5 to 30 volts DC

Remote Turn-on Current Draw:
Contact Closure: 1.5 mA

FEATURES

- Magnetic shielding steel enclosure
- 9' grounded 3-wire #12 line cord
- 8 grounded AC outlets on rear panel (6 switched, 2 always on)
- Front panel courtesy receptacle
- Advanced *Series Mode* surge protection
- Advanced *Impedance Tolerant* EMI/RFI filtering
- *SurgeX ICE* inrush current elimination technology
- *COUVS* catastrophic over/under-voltage shutdown
- Remote turn-on
- Thermal circuit breaker overload protection
- Self-test circuit with visual indicator
- 10-year warranty
- Made in U.S.A.

TECHNICAL DESCRIPTION

The SX1120RT shall be a one-rack-space unit in a magnetic shielding steel enclosure. It shall operate from 120 volts AC and have a 9-foot, grounded, 3-wire #12 line cord. There shall be 8 grounded AC receptacles on the back panel, with 6 switched and 2 always on. The unit shall have a front-panel courtesy receptacle and remote-control capability with a visual indicator. Overall dimensions shall be 1.75" H x 19" W x 10.5" D. Weight shall be 11 pounds.

The SX1120RT shall have a load rating of 20 amps at 120 volts, a self-test circuit with visual indicator, and provide EMI/RFI filtering, inrush current elimination and catastrophic over/under-voltage shutdown. It shall meet Federal Grade A, Class 1, Mode 1 guidelines for powerline surge suppressors and withstand at least 1000 occurrences of surge pulse voltages up to 6000 volts.

5 V DC Applied Voltage: 0.1 mA
12 V DC Applied Voltage: 1.5 mA
24 V DC Applied Voltage: 5.0 mA

Auxiliary Relay Contact Rating: 30 Volts at 1 Amp

LED Output: 12 volts DC, maximum 20 mA (resistor required)

Dimensions: 1.75" H x 19" W x 10.5" D (4.5 x 48.3 x 26.7 cm)

Weight: 11 lbs (5 kg)

Temperature Range: 5º to 35º C

Humidity Range: 5% to 95% R.H., non-condensing

Agency Listings: ETL and cETL (UL 1449, 2nd edition; CSA C22.2 No.8-M1986, R2000)

* 1.2 x 50 µs pulse, industry standard combination wave surge, as per IEEE C62.41

Specifications subject to change without notice. SurgeX is a division of Electronic Systems Protection, Inc.

This product, including its components and/or processes carried out thereby, are covered by one or more of the following: U.S. Pat. No. 4,870,534. 4,870,528. 6,728,089. 6,744,613. 7,068,487. Can. Pat. No. 1,333,191. 1,332,439. Other Patents Pending.

All SurgeX® products are backed by a 11 year warranty

A Simple Smoke-Detector Interlock Box

J. Olsen

11 August 2010

Introduction

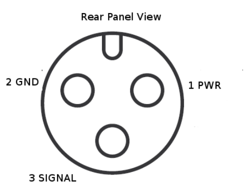
There is a need for a simple, low cost rack protection system (RPS) that will interface to a smoke detector and control an interlock signal. If smoke is detected in the rack the RPS box will drop the interlock and a separate AC distribution unit will interrupt power to rack components. In some racks a UPS is also used, so the proposed RPS interface unit must also provide a contact closure output that will force the UPS to immediately power off and disconnect if smoke is detected.

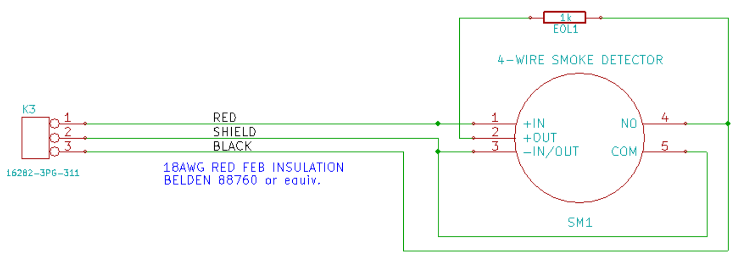
Requirements

- Simple, hardware only. No programmable logic, CPU, or software may be used.
- Uses a standard 4-wire smoke detector (photometric or ionization type)
- Powered from 120VAC
- 12VDC interlock output
- Interlock LED indicator
- UPS Emergency Power Off (EPO) contact closure output
- 1U rack mounted chassis
- Pushbutton reset
- Audible alarm indication

Circuit Description

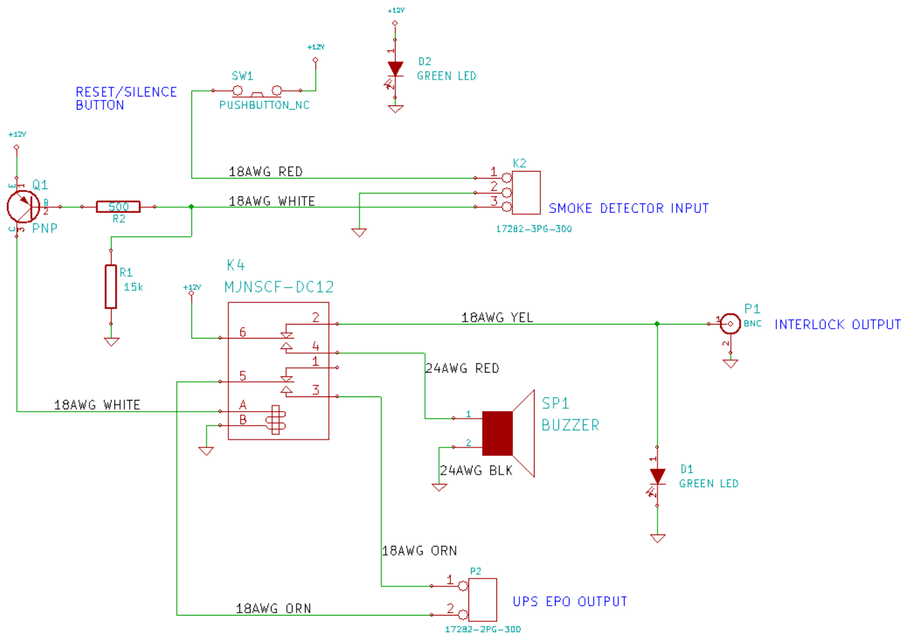
A standard 4-wire smoke-detector requires 12VDC and provides a set of normally-open contacts. When smoke is detected the contacts close and remain closed until the detector power is interrupted. A normally-open contact smoke detector has one major problem -- it is not possible to distinguish between a normally operating smoke detector and one that has become disconnected from the RMI. Therefore a pull-up resistor has been added to the smoke dectector as follows:





So normally the RMI will see a 1k ohm pullup to 12VDC on connector K3 pin 3. If the detector trips connector K3 pin 3 will be connected hard to ground. If the detector is not plugged in pin 3 will be floating. (Note that smoke detector pins 1 and 2 are shorted internally.)

The RMI circuit is shown below:



A PNP power transistor and bias resistors are used to drive a DPDT relay. If the detector is not plugged in current flows through R2 and R1 and saturates the transistor, energizing the relay (fault condition). If the detector is plugged and in normal operating mode in its 1k pullup resistor forces the transistor into cut-off an de-energizes the relay. If the detector trips current will flow through R2 and R1 and energize the relay.

Detector	Relay	Interlock Output	UPS EPO
Normal	off	+12VDC	Open
Tripped	on	0V	Closed

Press and hold the normally-closed button for a few seconds to reset the smoke detector.

A small low-wattage 12VDC switching supply powers the circuit.
The output is current limited to 1A.

Cost

Total cost for this unit is approximately $200 plus labor to assemble.

Rec. 6/19/91

Safety Analysis of the D0 High Voltage System

[redacted] M. Johnson

June 1991

First, some background in the physiology of shock hazards. The shock hazard is independent of voltage; it is only dependent on the current. Thus, a 5 KV supply delivering 1 mA is no more dangerous than a 50 volt supply delivering the same current. All that is required is sufficient voltage to drive the current through the resistance of the body. Data indicate[1] that the median sensation threshold for a sample of 167 adult men to be 1.086 mA. At currents up to 3 mA there is only a mild sensation and currents up to 10 mA are painful but not dangerous[2]. The paralysis threshold where one cannot let go of a circuit is taken to be 10 mA.

Shocks are dangerous to life when they cause ventricular filibration. The current where this occurs for 0.5% of the population is 75 mA DC. This is not the entire story for people can sustain much higher currents for short periods of time. Data show that the danger from momentary current pulses is proportional to I^2t where I is the current in amps and t is the time in seconds that the current is flowing[3]. Ref 3 indicates that the maximum safe value of I^2t for a 150 pound man is 0.027. Ref 3 also indicates that the body internal resistance is between 200 and 1000 ohms.

The normal maximum current from the D0 supply is 1 mA for the 5.6 KV supply and 3 mA for the 2 KV supply. Shorting any supply with a 1 K ohm resistor (representing the human body) causes the over current trip to trip immediately. If the over current trip circuit is disabled and the supply shorted with a 1 K resistor, the supply trips on overvoltage. The measured voltage across the 1 K resistor for several different supplies ranged from 8.6 volts to 39 volts so this is clearly not an overvoltage condition. What happens is that even with the current trip disabled, there is a 4.65 K resistor between the low side of the transformer and ground. All current must flow through this resistor so when the supply is delivering a lot of current, the

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[1] Dalziel, Charles F., "Electric Shock Hazard", *IEEE Spectrum*, Feb, 1972.

[2] Lee, Ralph H., "Electrical Safety in Industrial Plants", *IEEE Spectrum*, June, 1971.

[3] Kleronomos, Chris C. and Cantwell, Edward C.,"A Practical Approach to Establish Effective Grounding for Personnel Protection", IEEE Conference Record Paper, CH460-5/79/0000-49, 1979.

transformer is forced below ground potential which in turn forces the voltage readback to the comparator to go negative. The comparator's normal operating voltage is from -0.3 to 36 volts so when it sees a negative voltage less than 0.3 volts, it trips. This trip works on all 3 supply types. The typical trip time is around 200 mS. Using a conservative value of current as 50 mA and a trip time of 250 mS gives $I^2t = 6.25\ 10^{-4}$. Dividing this into 0.027 gives a safety factor of 43. While these currents can cause a painful sensation, they are not at all dangerous. Note that this involves a double failure - a failed current trip circuit and a person touching a high voltage lead.

A second area of concern is the stored charge. This is what normally causes the painful sensation when one touches a high voltage supply. Even small capacitances can deliver substantial amounts of current through the low resistance of the human body. Since this is a pulsed shock, one can calculate I^2t for this case. The current from a capacitor is

$$I = \frac{V0}{R} \exp[-\frac{t}{RC}]$$

where V0 is the applied voltage, R is the discharging resistance and C is the capacitance. Since I is a function of time we compute I^2t by integrating I^2dt from 0 to ∞ This gives

$$I^2t = \frac{V0^2\ C}{2\ R}$$

For V0 = 5.6 KV, C= 3 nF and R= 200 Ohms (lower limit of body resistance) we get $I^2t = 2.35\ 10^{-4}$. Adding the supply value from above to this gives $8.55\ 10^{-4}$. Dividing this result into the maximum safe value for this quantity (0.027) gives a safety factor 32. One must increase the capacitance by a factor of 100 before approaching the lower limit of the a health hazard. Again, this is the safety factor with a failure in the current trip circuit. With no failures. the value of $I^2t = 2.35\ 10^{-4}$ and the safety factor is 115. The 3 nF capacitance is the output filter capacitor. The other 3 nF capacitors have 100 K resistors in the current path so they make a negligible contribution to I^2t.

How does this shock hazard compare with our everyday experience? A good example is the shock from walking on a carpeted floor and then touching a door knob. The voltage that can develop is a function of many things including the humidity and the carpet resistance. The maximum voltage that can be developed is around 20 KV and the capacitance of a human is about 120 pF[4]. Putting these values into the above formula for I^2t gives $I^2t = 1.2\ 10^{-4}$ which is about one half of the value for the power supply with no failures. In other words the maximum shock from a normal power supply is about twice as large as the maximum shock from walking on a carpet.

When the supplies are connected to long cable runs, the danger from the charge stored in the cable increases greatly. The D0 high voltage cable has a capacitance of 30 pF/foot. Cable lengths of 135 feet are used throughout the detector. In the worst cased a single supply feeds up to 20 cables through two levels of fanout. Twenty 135 foot cables gives a capacitance of 81 nF or 27 times the supply capacitance. This reduces the safety factor from 115 to 4 which is still safe. This safety factor is for the maximum supply voltage (5600 V). The detector usually runs at 2500 V and the maximum allowed voltage (voltage limit pot on the HV supply) is 3000 V. Since the shock hazard goes as V^2, this increases the safety margin by a factor of 4 giving a total safety margin of 16. Note that the contribution from a failed current trip is small (10%) compared to the cable capacitance for this case.

6/19/91
Safety analysis looks OK. There is no apparent electrocution hazard. Also, as an extra precaution the equipment is housed in grounded metal enclosures and all HV is transported via shielded cables (coax) with the shield connected to ground.

A.F. Visser

Copy to G. Ryk
R. France
E. Dleman.

[4]Digital Equipment Corporation, "Installation Guide for Computer Systems".